Demonstration and Field Trial of a Scalable Resilient Hybrid ngPON

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Abstract: The built multi-layer SARDANA prototype proves the feasibility of extended hybrid DWDM/TDM-XGPON FTTH networks with resilient optically-integrated ring-trees architecture, supporting broadband multimedia services.

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1. Introduction
Current developments on new FTTH network architectures and technologies aim at enabling universal end-to-end communications with substantial increase in terms of bidirectional capacity, connected users and distance reach, as well as incorporating enhanced scalability, resilience, security, service integration and other key functionalities.

The novel hybrid ring-tree DWDM/TDM-PON test-bed, that has been implemented in the SARDANA project (Scalable Advanced Ring-based passive Dense Access Network Architecture) [1,2], demonstrates the feasibility of a transparent passive approach of what is today known as metro-access convergence. It consists of the organization of the optical distribution network as the aggregation of TDM access trees passively connected through a WDM bidirectional ring, via cascadeable Add&Drop Remote Nodes, operating as a resilient all-optical TDM-over-WDM overlay. The proposed topology concentrates the electronic equipment at a unique Central Office, whilst simplifying the customer premises equipment and PON.

2. Test-bed.
Fig. 1 shows the system diagram of the Sardana test-bed, following the layered model, from bottom to top: the ring-tree PON optics, the WDM routing and protection modules, the colourless PHYsical transceivers, the MAC, the Ethernet and the service layers. Five ONUs have been assembled for the demo.

The OLT, build up in a 19" rack, is composed of the optical amplification stages, the pump source, the WDM multiplexing, the Protection&Monitoring system, the coloured burst-mode transceivers, the MAC and the Ethernet layers and OMCI control. The MAC logic implements, with 10G Serdes and FPGA, 10Gbit/s SXGPON framing and data adaptation for downstream, and 2.5Gbit/s SXGPON framing and data adaptation for upstream, and the PON MAC functions required for ranging and capacity allocation of the ONUs. It provides interfaces to network service nodes, to management and to the Sardana optical systems. A 10Gbit/s CX4 electrical Ethernet interface connects OLT to the service nodes that supplies IP/Ethernet based Internet, IPTV and Videoconferencing services. Different VLANs are used to separate services from each other.

The 10Gbit/s serialized output drives the coloured DFB-MZM transmitters at the C-band in the odd 50GHz ITU grid; they include frequency dithering for Rayleigh scattering reduction and modulation control, fixing the downstream extinction ratio (ER) to 3.5 dB. The RX is based on burst-mode PIN-TIA with SQRT compressor.

The protection module routes every wavelength channel to the East or West side of the PON ring, depending on the corresponding RN distances and the ring protection conditions. It is based on an array of mechanical switches, with total insertion loss below 2 dB, controlled by the Protection& Monitoring module.

Four AWG multiplexers (East/West, Down/Up-stream) set the WDM multiplex, passing through DCF modules compensating 40Km of SSMF, optical booster/pre-amplifier and pump couplers. The output power is 7 dBm per channel. The pump module, based on a Keopsys Raman fibre laser at 1480 nm, provides 1 W to the upstream fibres.

The central ring, doubled for downstream and upstream, connects the Remote Nodes that drop/add two 100 GHz adjacent wavelength channels to two access trees. The ring fibre length ranged from 20 to 100 Km. The demo test-bed includes three RN (the rest are emulated with attenuators). The RN provide optical amplification of 10-16 dB, depending on the location, to overcome the extended power budget requirements of the extracted channels, by means of internal EDFs remotely pumped from the OLT. Each RN drops a fraction of the pump power travelling through the upstream ring [3]. The bypass insertion loss of the RNs is only about 1 dB, guaranteeing ring scalability.

Every access TDM tree distributes a wavelength channel to the single-fibre single-wavelength colourless ONUs. Three of them are based on RSOA, in simple TO-CAN package, modulated at 2.5 Gbps with preemphasis, providing upstream ER of about 7dB, and silent level of -12 dB at burst disable. The APD received 10 Gbps...
downstream data counteracts the RSOA gain to reduce the down ER crosstalk from 3.5 dB to 1.5 dB, thus being able to reuse it. The optical ONU gain, including the 30:70 coupler, is about 12.5 dB, launching -4 dBm. Other ONU are based on C-band tunable laser externally modulated at 10G, on SOAREAM and on SFP transceiver.

The upstream data is replicated to both sides of the ring by the RN, reaching the OLT, where it is preamplified, WDM demultiplexed and direction-selected by the protection module, lead to the RX. To deal with its bursty nature, specific optical gain clamping techniques have been developed, keeping the transient distortion below 1 dB. Extra 2 dB of gain were obtained in the last upstream links because of Raman amplification.

Three different test-bed public demonstrations, integrating the equipment developed by the seven partners, where made: the first one in Espoo (Finland) in October 2010, the second in Lannion (France) in January over the metropolitan 18 Km ring cable, and the third one in the FTTH’2011, in Milan in February.

3. Field Trial

The Sardana network was installed over open fibre network in the Bretagne Lannion area (France) managed by the Media@Network cluster, in January. An 18 Km 12-fibre ring connected the ImagineLab (where the OLT and the main equipment were installed), the ENSSAT (with a RN and ONU), and Orange Labs (with another ONU through a distribution tree), drawn in Fig. 2.

The total ring loss was about 9 dB, including the losses of the SC/APC connectors at each location patch panel. Extra 20 Km and 5 Km fibre spools where added between the OLT and the first and last RNs respectively, at ImagineLab, composing a 43 Km ring. The single-fibre tree had a length of 5 km, and a splitting of 1:16 (plus variable attenuator). A HD Video-Conferencing was established for live communication with the remote ENSSAT location (at 8.7 East /8.8 km West).

Fig. 1: Sardana testbed subsystems scheme (left), demo setup, downstream east spectrum, burst mode upstream frame, DS and US eyes (right).

Fig. 2: Field trial network scheme and Lannion ring map (in yellow).
4. Tests and Results
The performed measurements over this test-bed, at the application, Ethernet, MAC and PHY layers, showed the following features:

- Neutral multi-operator/service: different standards, bit rates and protocols were simultaneously transported through the Sardana network transparently over the wavelength channels. Fig. 3 summarizes the obtained performances in terms of ring length, maximum number of ONUs and down/up bit rates.
  - 10G/2.5G XGPON1 MAC with 2 RSOA ONUs in a tree.
  - Bidirectional 10G Ethernet with tunable lasers at ONU and OLT.
  - Standard 1G Ethernet SFPs with RSOA transceiver and evaluation board.
  - Standard 1G Ethernet SFPs with commercial RSOA SFP transceiver, as pure-WDM-PON.
  - Standard 1G Ethernet SFPs, with fixed lasers at 1550.12 nm (up/down with slight drift).
  - 10G/10G 231-1 PRBS with SOAREAM ONU.

- High-bandwidth real-time bidirectional HD multimedia services, over the different WDM channels:
  - HD-Video downstream broadcast and HD-Video upstream, from ONU to server.
  - HD-Video Conferencing; a point-to-point VLAN is configured between two ONUs by creating two 1:1 VLAN from OLT to two ONUs VC service ports that map to VC-GEMportIDs across the SXGPON.
  - Service control over OMCI (CPC-to-CPC).

- MAC ranging over differential 6 Km of two TDM ONU channels in a XGPON frame (70 Km in separate tests).

- ONU colourlessness: the RSOA ONU22, first operating at the 1551.32, was exchanged with the other RSOA ONUs; the service continued the operation correctly, with sensitivity differences below 2dB.

- The total power budget, considering the metro ring and the access trees, is about 35 dB, for the reference 10G/2.5G channel. The downstream and the upstream are balanced by means of the downstream ER and the ONU splitter. Sensitivities were measured at 10^-6 BER, where pixelation starts to be visible.

- 1024 maximum number of homes was practically emulated, adding optical attenuators and dummy channels.

- Rayleigh backscattering and reflection tolerance: with the implemented techniques, like wavelength dithering, the impairment was negligible up to 6 Km of drop fibre, and using angled connectors.

- Resiliency; the OLT RX LoS alarms with fibre disconnected between RNs and between OLT and RN, triggering the P&M (Protection and Monitoring) system to reroute the channels. Protection switching proved not to interrupt nor impair the Ethernet connection: video transmission quality remained unchanged to the eye, since switches activation is around 20 to 25 ms. The differential sensitivity between normal mode and protection mode of the different channel transmissions were below 3 dB.

4. Discussion and conclusion
The implemented test-bed demonstrates truly-passive extended PON, fundamental resiliency, XGPON1 rates, wavelength-agnostic single-fibre ONUs, neutral multi-operability optical infrastructure and cost efficiency in practical condition. The technological advances developed in the project, like distributed A&D, remotely pumped optical amplification, wavelength dithering, colourless reflective ONU with optical downstream cancellation and opto-electronic equalization and 10G/2.5G xGPON MAC, enable the feasibility of the new network concept for its application in future PON migrations. Enhanced performances can be pursued with improved RSOA or tunable laser technologies, with burst-mode RX and FEC coding and, especially, with mass-production capability.

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5. References